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SYNOPSIS

This paper briefly reviews the various liner materials, their properties and applications to prevent contaminate spread into the groundwater. Following this, two cases have been described that cite the use of two liner types for this purpose. One case provides the details of designing the reinforced CPE liner and its under-drainage system to store the fluids at a new petrochemical plant. The second case provides the details of designing and constructing a soil-bentonite liner for aerated lagoon facilities.

INTRODUCTION

Liners to control liquid seepage have been used for a long time e.g. bitumen-lined sewer drains were used in Mesopotamia over 3000 years ago. In recent years concrete, asphalt, soil-cement, clay and other types of liners have widely been used for canals, reservoirs and waste disposal ponds and lagoons. The use of liners for pollution control to impound different types of wastes has, recently, been increasing to meet various pollution control regulations.

Pollution control liners are mainly required to prevent contaminate migration to the surrounding environment due to excessive leakage. Table 1 lists various liner materials.

TABLE 1 - LINER MATERIALS (FOLKES, 1982)

CLASS	TYPICAL MATERIALS	REMARKS
Compacted fine-grained	Local clayey soil	Porous, discontinuous liner, economical, typically 0.3-1.2m thick.
Admixes	Bentonite Soil cement Hyraulic asphalt concrete (HAC)	Low permeability binder mixed in with native soil typically 5-10cm thick layer
Polymeric membranes		
Thermoplastics	Polyvinyl chloride (PVC) Chlorinated polyethylene (CPE) Chlorosulfonated polyethylene (CSPE) (Hypalon)* Elasticized polyolefin (ELPO)	Continuous liner, discontinuous where damaged, relatively expensive, typically 0.5-2.6mm thick, may be reinforced with polyester scrim
Vulcanized elastomers	Butyl rubber Neoprene (CR) Ethylene propylene diene monomer (EPDM)	
Crystalline thermoplastics	Low density polyethylene (LDPE) High density polyehtylene (HDPE)	
Spray-ons	Catalytically blown asphalt Emulsified asphalt	Continuous liner, discontinuous at pinholes, cracks, typically 4-8mm thick
Sealants	Polyacrylamide Liquid viny polymer	Sprayed, dusted or ponded, may result in nonuniform coverage
Chemisorptives		Function is to absorb contaminants, experiments

* Hyplon is DuPont's Registered Trademark for its Synthetic Rubber

The two main properties that should be considered in liner design are that (i) the liner permeability and (ii) the liner and stored fluid compatibility. Figure 1 summarizes typical ranges of laboratory and field hydraulic conductivity (permeability) of various liner materials.

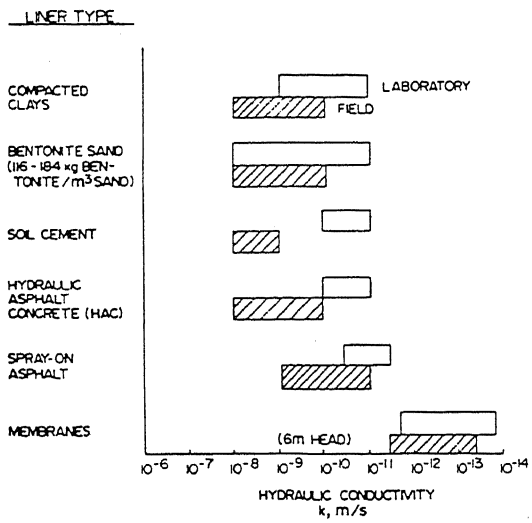


FIGURE 1 - Typical Ranges of Laboratory and Field Hydraulic Conductivity of Various Liner Materials (Folkes, 1982)

Folkes (1982) indicates that for a meaningful comparison of liner materials seepage velocities should be considered along with liner thicknesses. This is shown in Table 2 where seepage velocities for 1m total head on usual liner thicknesses is summarized.

TABLE 2 - SEEPAGE RATES FOR TYPICAL LINER THICKNESS

LINER MATERIAL (TYPICAL THICKNESS)	FIELD SEEPAGE RATE FOR 1M TOTAL HEAD DIFFERENTIAL, m/s
Compacted Clays (600mm - 1200mm)	3×10^{-8} to 8×10^{-11}
Bentonite - Sand (50mm - 150mm)	2×10^{-7} to 7×10^{-10}
Soil Cement (100mm - 150mm)	10^{-7} to 8×10^{-9}
Hydraulic Asphalt Concrete (50mm - 100mm)	2×10^{-7} to 9×10^{-10}
Spray-On Asphalt (4mm - 8mm)	2×10^{-8} to 3×10^{-9}
Polymeric Membranes (0.5mm - 1.0mm)	9×10^{-9} to 6×10^{-11}

LINER AND STORED FLUID COMPATIBILITY

The liner material may be chemically affected by the contained fluid. This may either result in a liner breakdown and/or cause increased liner permeability. Table 3 provides some data on the effects of industrial wastes on soil and admix liners while Table 4 summarizes information on liner-industrial wastes compatibilities. There is a lack of information on the long term liner and the stored fluid compatibility data. Such work should therefore be carried out on specific projects.

This paper presents cases for two liner types. In one case a reinforced chlorinated polyethlene (CPE) liner was used to protect groundwater at a petrochemical plant and in the second case, a soil-bentonite underseal was used as a seepage control barrier for aerated lagoon facilities.

CASE 1 - REINFORCED CPE FLEXIBLE LINER TO PROTECT GROUNDWATER AT A PETROCHEMICAL PROJECT SITE

At Union Carbide's ethylene glycol plant site in Central Alberta, Canada, the land form is that of a ground moraine, with glacial deposits generally overlain by a thin veneer of clays, silts and sands. The bedrock underlying the till stratum consists mainly of soft weathered sandstones and siltstones interbedded with clay shales. The groundwater movement takes place through pervious members of the till and bedrock formation. The water is confined by the till resulting in artesian condition. The surficial soil thickness varies from 4m to 12m. Site specific details are further provided by Sharma (1983) and Pritchard et al (1983).

The near surface artesian groundwater is a source of water for cattle in the area. It therefore, became essential to protect this water from any undesirable seepage from the stored fluid within the plant boundary. Among many liquid storage ponds, the waste water pond was of concern for the groundwater protection. The chemical composition of the fluids stored in the pond was diluted sulphuric acid about 10%, caustic chemicals about 5%, glycol about 5% and small amounts of diluted ethylene oxide. The environmental requirements set for these ponds was that no fluid was allowed to seep into the groundwater. It was therefore decided to provide a liner in the pond and to establish a long-term groundwater monitoring system at the site.

TABLE 3 - EFFECT OF INDUSTRIAL WASTES ON SOIL AND ADMIX LINERS*

Liner material	Acidic waste (HNO_3, HF, HOAC)	Alkaline waste (spent caustic)	Lead (low lead gas washing)	Oily waste: Aromatic oil	Oily waste: Oil pond 104	Pesticide (weed killer)
Compacted fine-grained soil 305 mm thick	Not tested	Measurable rate of seepageage $v_s = 10^{-10}-10^{-9}$ m/s, waste penetrated 3-5 cm after 30 months (a)		$k=1.8x10^{-10}$ $k=2.4x10^{-10}$ $k=2.6x10^{-10}$ (tests on soil after 30 months)	+	+
Soil cement 100 mm thick	Not tested			No measureable seepage after 30 months		
Modified bentonite and sand (2 types) 127 mm thick	Not tested	Measureable seepage after 30 months, channelling of waste into bentonite(b)			Failed (waste seepage through liner)	+
Hydraulic asphalt concrete (6 mm tick	Failed	Satisfactory	Waste stains below liner asphalt mushy	Not tested	Not tested	Satisfactory
Spray-on asphalt and fabric 8 mm thick	Not tested	Satisfactory	Waste stains below liner	Not tested	Not tested	Satisfactory

+Same as (a)

+Same as (b)

*Summarized by Folkes (1982) from data originally presented by Haxo (1981)

TABLE 4 - LINER - INDUSTRIAL WASTES COMPATIBILITIES*

Liner Material	Caustic petroleum sludge	Acidic steel-pickling waste	Electro-plating sludge	Toxic pesticide formulations	Oily refinery sludge	Toxic pharma-ceutical waste	Rubber and plastic
Polyvinyl Chloride (oil resistant)	G	F	F	G	G	G	G
Polyetheylene	G	F	F	G	F	G	G
Polypropylene	G	G	G	G	G	G	G
Butyl Rubber	G	G	G	F	P	F	G
Chlorinated Polyethylene	G	F	F	F	P	F	G
Ethylene propy-lene rubber	G	G	G	F	P	F	G
Hypalon+	G	G	G	F	P	F	G
Asphalt concrete	F	F	F	F	P	F	G
Soil cement	F	P	P	G	G	G	G
Soil asphalt	F	P	P	F	P	F	G
Asphalt membranes	F	F	F	F	P	F	G
Soil bentonite (saline seal)	P	P	P	G	G	G	G
Compacted clays	P	P	P	G	G	G	G

+P = poor, F = fair, G = good
+Registered trademark of DuPont
Registered trademark of American Colloid Company

*Stewart (1978) as Cited by Penttinen (1984)
+ Hypalon is DuPont's Registered Trademark for its Synthetic Rubber

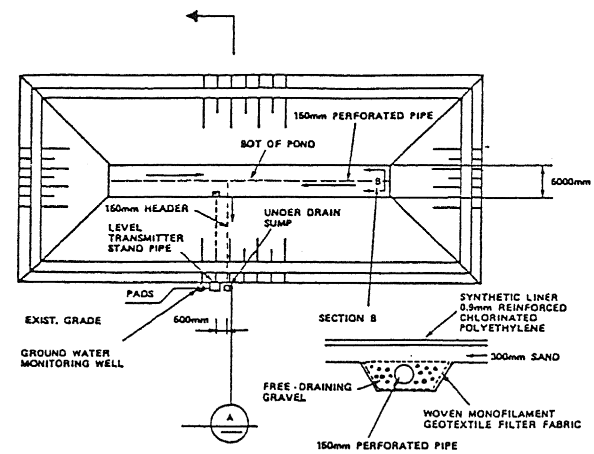
POND LINER

The selection of liner material was based on the requirement that (i) the liner should have low permeability and (ii) should be resistant to chemical attack from stored fluid and (iii) should be resistant to ultraviolet radiation over 20 years design life. A review of Figure 1, Tables 2, 3 and 4 indicated that based on performance and economics chlorinated polyethelene was found to be the most suitable liner for the ponds. Furthermore, there existed a potential for uplift pressure at the base of liner due to the hydrostatic pressure. Therefore, it was decided to use reinforced feature in the liner. Thus, the reinforced chlorinated polyethylene liner was selected for the project.

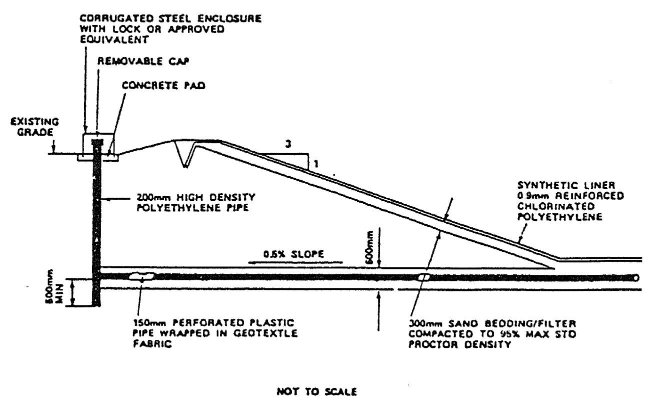
Figure 2 shows the details of the liner installation system. Below this liner a 300mm sand bedding was placed both on the sides and at the bottom of the pond. A gravel-filled trench was also placed at the pond bottom along its centerline. A 150mm perforated drain pipe wrapped in woven filter fabric was placed at the bottom of the trench. This perforated-drain pipe was sloped towards the pond center and connected to a 200mm sump through a pipe. This under-drainage system was installed to serve two purposes: The first purpose was to relieve about 4m of groundwater pressure at the pond base below the liner. This became important because the pond was required to be operated often at low levels. Thus the groundwater pressures could be relieved by pumping from the sump before lowering the water level in the pond. The second purpose of this under-drainage system was to periodically collect water samples for laboratory testing to detect any contaminant leakage from the process waste water pond.

GROUNDWATER MONITORING

Groundwater monitoring stations were installed across the site. These stations were located on four sides of the pond and at some distances away from the pond to measure the upgradient and downgradient underground water quality due to the presence of the pond. Figure 3 shows the typical details of the groundwater monitoring station. This consisted of two or three piezometers located at different groundwater sources. These groundwater monitoring stations were installed approximately one year prior to plant startup. Groundwater levels and water samples have since been taken and analyzed periodically. The overall system has been operating successfully for approximately the past five years.



(a) Plan of Process Waste Holding Pond



(b) Section AA to Represent Under-Drainage System

FIGURE 2 - Details of Pond Liner and Under-Drainage System

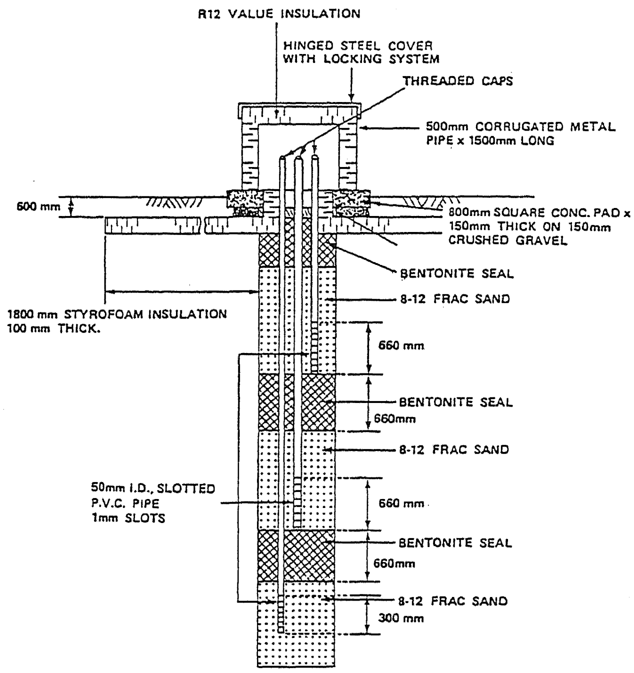


FIGURE 3 - Typical Groundwater Monitoring Station Design

CASE 2 - SOIL-BENTONITE LINER FOR AN AERATED SEWAGE LAGOON FACILITY

The second case history is that of a soil bentonite underseal seepage control barrier installed in aerated lagoon facilities constructed at Wawa, Ontario. The predominant soils at the site of the lagoon facilities consist of highly permeable coarse sands and gravels. The insitu permeability of the natural sands and gravels was estimated to be in the range of 10^{-1} cm/sec and therefore can be considered permeable. The existing adjacent lagoon system has had reported leakage problems and it was proposed to construct the new cells with a high density polyethylene liner. However, a soil-bentonite liner was selected on the basis of economics.

GROUNDWATER TABLE

The soil and groundwater conditions at the site of the aerated sewage lagoons were reported by Trow Inc. in a report dated May 1, 1986. The water table at the time of the geotechnical investigation was approximately 1.0 metres below natural ground surface and approximately 1.0 metres above the proposed cell base. The groundwater table was permanently lowered about 1 metre below the bottom elevation of the sewage lagoons by constructing a perimeter drainage ditch along the east and north sides.

LABORATORY TESTING

Grain size analysis tests indicated that the coarse sand and gravel contained about 50 percent gravel up to 75mm diameter, 45 percent sand, and less than 5 percent clay and silt size particles. The stripping material contained 30 percent gravel up to 30mm diameter, 43 percent sand and 27 percent silt and clay size particles. The stripping material also contained organic material. However, the amount of organics in the sample was not considered a problem insofar as imparing the performance of the soil bentonite liner.

Two (2) laboratory permeability tests were conducted on blended mixtures of gravel and stripping with four (4) and six (6) percent sodium bentonite. Soil-bentonite mixtures were brought to the desired moisture content and then compacted in a 100mm diameter constant volume permeameter at Standard Proctor effort. The mixtures were then saturated and permeability tests conducted using the constant head method.

Since the pH of the stored fluid in sewage lagoons ranges from 6.0 to 8.0, a soil-bentonite liner will not be chemically affected by the stored fluids. In this case, laboratory testing was not considered necessary to confirm liner and stored fluid compatibility.

DESIGN OF SOIL-BENTONITE LINER

The design of the soil-bentonite liner was based on the results of permeability tests performed on different soil mixtures. The permeability testing summarized in Table 5 indicated that a low laboratory hydraulic conductivity could be attained by admixing bentonite and stripping material with the coarse sand and gravel. However, for this to translate into an effective soil-bentonite liner with a low field permeability, attention had to be given to design and construction methods. The design had to consider the thickness of the liner and cover materials, while construction had to consider such factors as spreading of bentonite, degree of mixing, amount and type of compaction and molding moisture content.

The design thickness of the soil-bentonite

TABLE 5 - SUMMARY OF PERMEABILITY TESTING

Permeability Test	Sample Description		Saturated Laboratory Hydraulic Conductivity (cm/sec)
A	Gravel:	70.5%	2.5×10^{-9}
	Stripping:	23.5%	
	Sodium Bentonite:	6.0%	
B	Gravel:	72.0%	3×10^{-9}
	Stripping:	24.0%	
	Sodium Bentonite:	4.0%	

NOTE: Cobblestones greater than 38mm diameter were removed prior to proportioning

TABLE 6 - CALCULATED SEEPAGE RATES

MIXTURE	ANTICIPATED FIELD PERMEABILITY (cm/sec)	LINER THICKNESS (mm)	SEEPAGE RATE* (m^3/yr/square metre)
A	1.3×10^{-8}	200	0.13
		300	0.09
B	1.5×10^{-8}	200	0.15
		300	0.10

liner was generally based upon the predicted seepage rates through the liner and the comparison of this rate to the allowable. The seepage rate through the liner is a function of liner thickness, permeability and the head of water contained. The seepage rates shown in Table 6 have been calculated based upon anticipated field permeabilities, liner thicknesses between 200 and 300mm and an assumed height of water in the lagoon above the top of liner of 6 metres. The field permeability of the two (2) mixtures have been anticipated to be one half of an order of magnitude higher than that shown in Table 5. Table 6 indicates that for a seepage rate as high as $0.15 m^3/yr/m^2$ to be acceptable, then the soil liner could be designed to be 200mm thick and containing four (4) percent bentonite. The required maximum hydraulic comductivity for the liner was specified at 5×10^{-8} cm/sec.

The selected liner thickness for the aerated lagoon facilities at Wawa was 200mm and the bentonite application rate of 5 percent by weight of soil. A 200mm thick surface cover consisting of locally available granular material was placed on top of the soil-bentonite liner. Figure 4 shows the Plan and Section View of the Final Liner Design.

QUALITY CONTROL

Construction of a soil-bentonite liner is not a routine construction operation. It requires a good knowledge of characteristics of the material and an

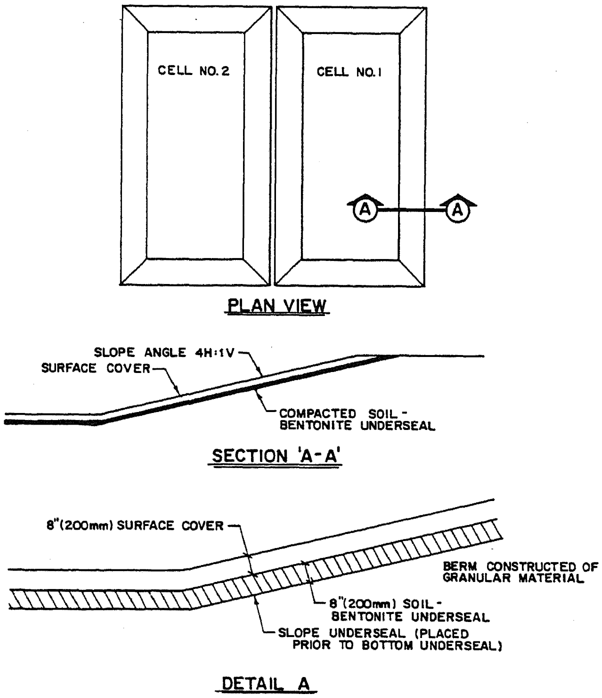


FIGURE 4 - PLAN AND SECTION VIEW OF FINAL LINER DESIGN

understanding of the importance of careful adherence to the specifications.

Regular compaction testing of completed sections of the liner was performed using a nuclear test gauge on backscatter mode to determine the compacted dry densities and molding moisture contents. The results of this testing is summarized in Figure 5 to 9, inclusive. The greatest variability in the compaction of the liner was for the east berm of Cell #1, which was the first section of liner completed. This section of liner was completed with densities as low as 85 percent of Modified Proctor Maximum Dry Density and molding moisture contents well dry of optimum. Even with these lower dry densities and molding moisture contents, the liner on the east berm of Cell #1 still met the specified permeability requirements of 5×10^{-8} cm/sec. The construction control on all other sections of liner was considerably improved with densities generally along the Line of Optimums.

A series of laboratory permeability tests were conducted on soil samples from the site. The samples were remixed in the laboratory and then compacted into the permeameter at moisture contents and densities simulating construction values. The results of this testing is also shown in Figures 5 to 9.

From a theoretical view point, the hydraulic conductivity of a compacted soil-bentonite (at the moisture contents and densities considered here) should decrease when either the moisture content or dry density increase. Therefore, any compaction test result shown in Figures 5 to 9 with a higher dry density or higher moisture content than any permeability test, should have the same or lower hydraulic conductivity. It was because of this theory that all permeability tests were conducted at the lowest densities and/or moisture contents typically achieved in the field.

All permeability tests conducted on soil samples from the actual soil-bentonite liner met or exceeded the maximum hydraulic

FIGURE - 5

SUMMARY OF DENSITY TESTING

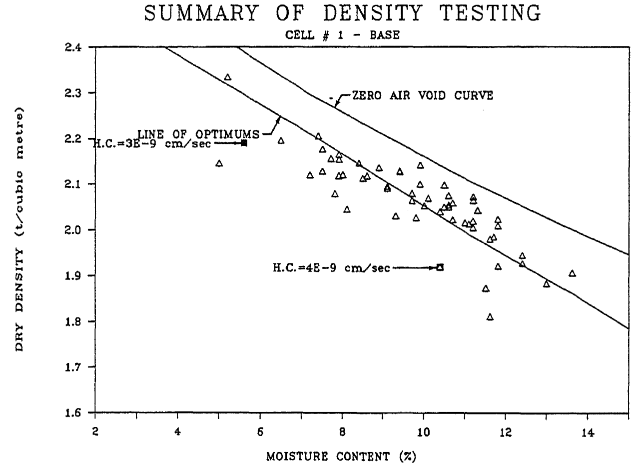


FIGURE - 6

SUMMARY OF DENSITY TESTING

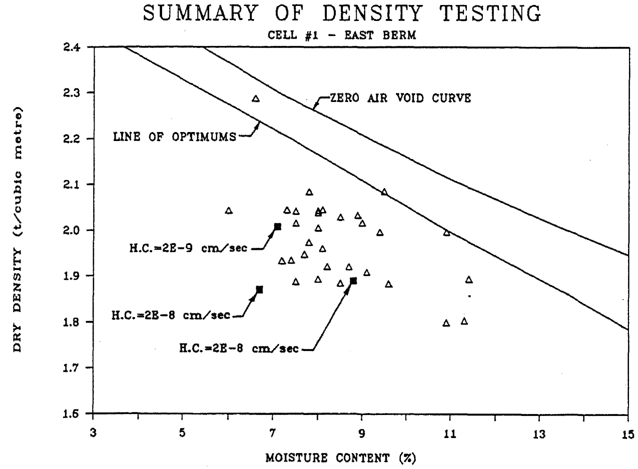


FIGURE - 7

SUMMARY OF DENSITY TESTING

CELL #1 - NORTH, WEST & SOUTH BERMS

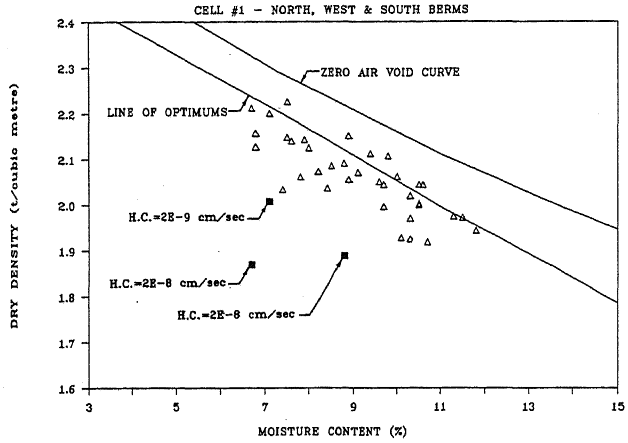


FIGURE - 8

SUMMARY OF DENSITY TESTING

CELL #2 - BASE

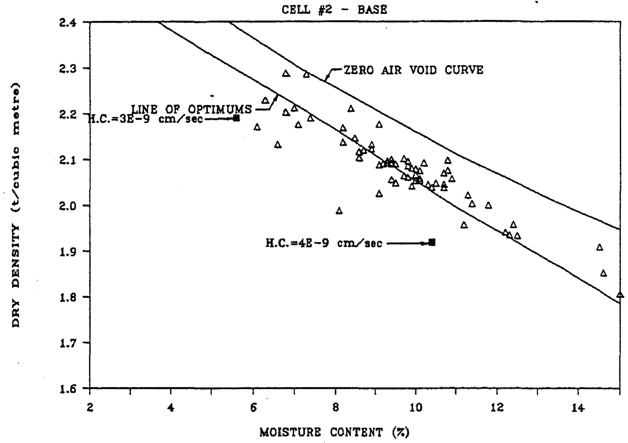
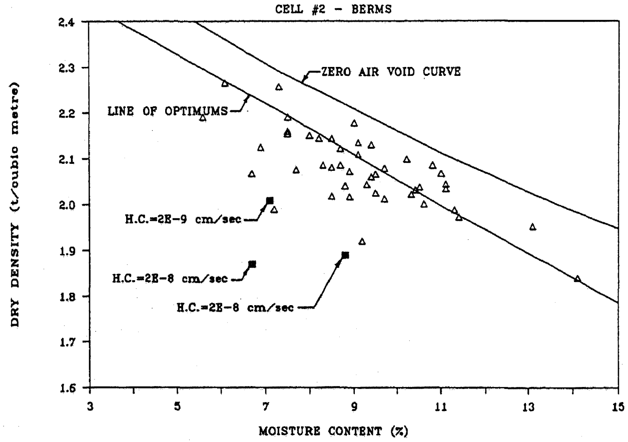


FIGURE - 9

SUMMARY OF DENSITY TESTING

CELL #2 - BERMS



conductivity for the liner of 5×10^{-8} cm/sec. As well, most field compaction test results were at moisture contents or densities greater than those used for the permeability tests. Therefore, it is considered that all portions of the soil-bentonite liner along the berms and base of the sewage lagoons met or exceeded the specified permeability requirements.

CONCLUSIONS AND RECOMMENDATIONS

Based on the two case studies cited here the following can be concluded:

.1) A reinforced synthetic (CPE) liner complete with an under-drainage system to solve uplift pressures was successfully installed at a new petrochemical site to protect the surrounding drinking water.

.2) Field monitoring of the piezometers, for about 5 years indicates that the liner and the under-drainage system has been performing effectively and have contained the stored fluid.

.3) A soil-bentonite type liner is an effective alternate method of constructing an economical liner to prevent contaminate spread into groundwater. This technique provides an economical solution to prevent contaminate spread into the groundwater.

.4) A soil-bentonite type of liner should not be constructed without adequate testing. This testing should include permeability testing with equipment capable of accurately measuring both flow in and out of the sample, and to determine liner and stored fluid compatability

.5) In addition to adequate testing, special care is also required in the construction of this type of liner. Thus, it is recommended that, where possible, contractors with experience in liner construction be employed to construct or assist in the construction of these liners.

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